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Accelerated Seaward Growth of Tidal Sand Bar during Giant Dyke Construction off the Mangyung River Mouth, West Coast of Korea

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The progress of giant dyke construction off the Mangyung and Dongjin rivers, has yielded enormous impact on the estuarine environment, both hydrodynamically and sedimentologically. Especially the inter-dyke gap in the northern Saemankeum area, 4 km wide between Yamido and Piungdo, has acted as an artificial tidal inlet. Due to such a changed geometry, tidal regime has been reversed from being flood- to ebb-dominated with a directional change from NE–SW to E–W. As a result, a large tongue-like tidal sand bar (named Saemankeum Bar) has conspicuously grown seaward through the artificial tidal inlet. The Saemankeum Bar composed of well-sorted very fine sands (3.0–3.5 ϕ) has grown at a rate of 1.63 km/yr for the past three years (1996–1998). Such a rapid growth of the sand bar is attributed to enhanced sediment supply derived from the degradation of former tidal sand bars at the mouth of the Mangyung River. Eventually the reworking of the tidal sand bars also caused the pre-existing tidal channels to be wider, deeper and more straightened. All of these phenomena well examplify the critical effect of artificial modifications on the natural estuarine environments.

INTRODUCTION

The extensive tidal flats along the west coast of Korea have historically been reclaimed in many localized places, mainly for rice farming. Since the early 1980s, bay-wide reclamations have commenced through national multi-purpose (agricultural and industrial) projects by constructing enormous dykes with the length of several to tens of kilometers at some large estuaries and embayments (Rural Development Corporation, 1996). The resultant environmental changes may well be striking and very pervasive. For example, sandy tidal flats, remaining after construction of the Daeho dyke crossing the former entrance of Seosan Bay, are currently suffering from marked erosion at an annual rate of −10 cm/yr (Lee *et al.*, 1999). The Shihwa dyke, constructed across the former mouth of Panweol Bay, has also raised a lot of problems with sedimentary facies changes and pollutant accumulation in the adjacent nearshore (Choi *et al.*, 1999; Lee *et al.*, 1999). Coping with such undesirable problems, the government has realized the importance to investigate in advance the environmental effects of dyke construction to avoid probable damage critical to coastal fishery and ecosystems. In this context, the construction of the Saemankeum dyke off the mouth of the Mangyung River is underway carefully with continuing endeavour to model and monitor a variety of environmental factors (Rural Development Corporation, 1992, 1995, 1996, 1997).

The tidal sand bars in the Mangyung estuarine environment have been documented to be subjected to large morphodynamic modifications derived from the ongoing construction of the Saemankeum dyke (Rural Development Corporation, 1998, 1999). The Saemankeum dyke would connect several islands off the Mangyung estuary amounting to 28,300 ha in reclaimed area and 33 km in total length at the completion (Rural Development Corporation, 1995). The resultant huge environmental changes impacting particularly to the sand deposition off the river mouth is of special interest to marine geologists as well as government agents. This is because the Keum and Mangyung rivers, the former located immediately north of the dyke (Fig. 1), are inferred to be the principal sources for coastal sands to the south via littoral drift which is reinforced during winter (cf. Reading, 1996).

Therefore, we studied recent behaviour of the tidal

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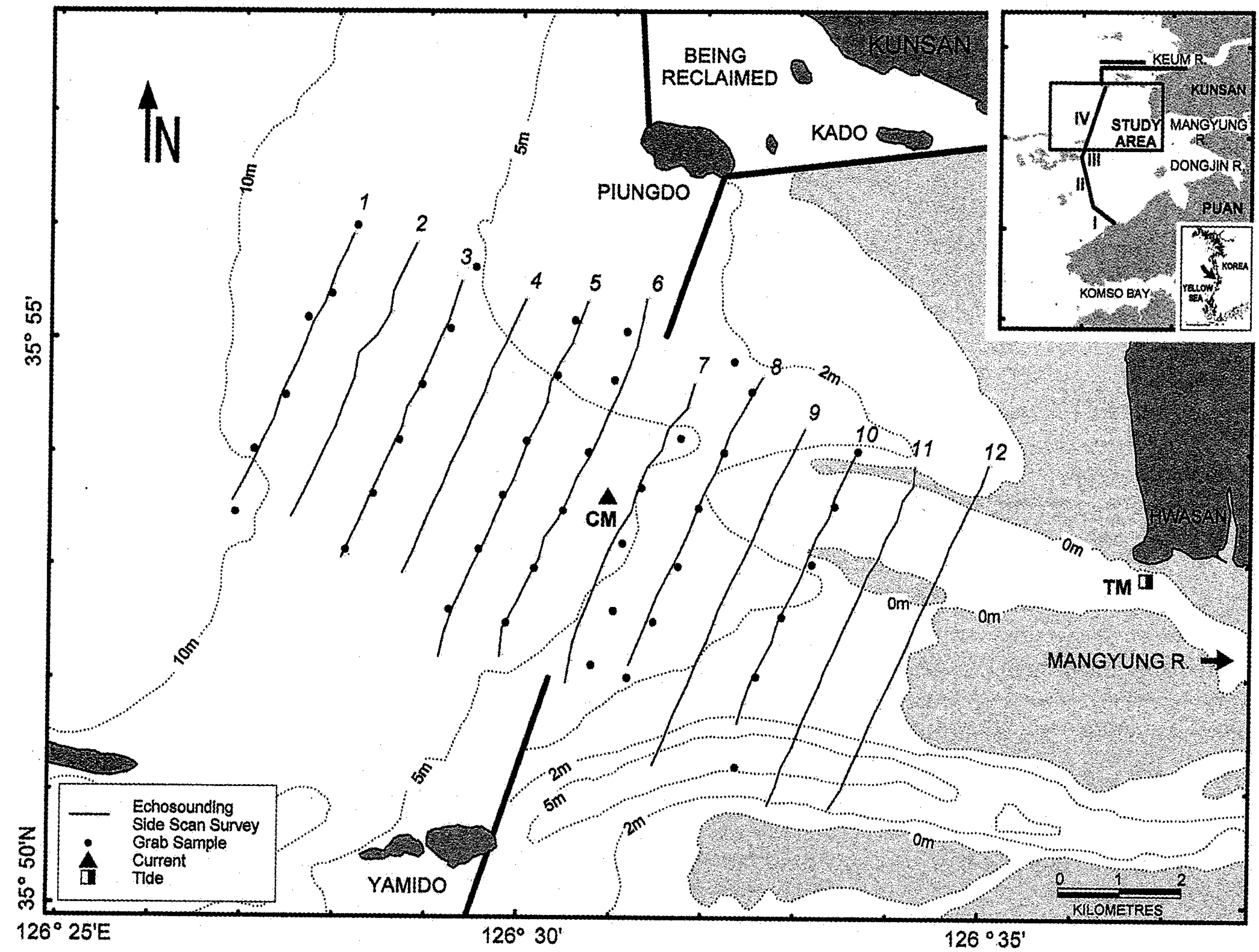

Fig. 1. Map showing the survey area in the Mangyung estuary. Light solid lines indicate the side-scan sonar and echosounding survey lines, whereas heavy solid lines the dykes in progress. Depth contours in meters are based on the chart data in 1992 (Hydraulic Office, 1992).

sand bars off the Mangyung River with respect to sedimentological and hydrodynamic processes during the construction of the Saemankeum. Our major purposes are to identify morphological changes and displacements of the estuarine bar-sand deposits, to relate those sedimentological characteristics to newly established hydrodynamical regime, and to suggest the cause and result of the dyke construction for depositional environments in the surrounding nearshore.

ENVIRONMENTAL SETTING

The study area belongs to an estuarine environment that receives considerable amounts of terrigenous sediments from the Mangyung and Dongjin rivers (Fig. 1). At the river mouth, tidal sand bars are elongated in a radiating pattern but predominantly NE-SW direction (Park *et al.*, 1991). Individual sand bars vary in length from 4 to 15 km and in width from 1 to 4 km, and generally have superimposed dunes mostly at the flat top (Park *et al.*, 1991). Some of them are subaerially exposed during the low tide. Tidal channels between the sand bars are usually 10–15 km wide with a maximum water depth of 25 m (Park *et al.*, 1991). The tidal sand deposits are demarcated by a distinct ravinement surface subparallel to the seafloor (Choi, 1994). The sand deposits locally reach up to 15 m in thickness (Kunsan Univ., 1994) and rapidly pinch out offshore. Instead, the Holocene transgressive mud is exposed to the seafloor seaward of the dyke. The occurrences of similar tidal sand ridges off the river mouth have been described elsewhere along the west coast of Korea (Off, 1963; Klein *et al.*, 1982; Park and Lee, 1994; Park and Yoo, 1997; Jung *et al.*, 1998).

Tide was semidiurnal with a mean tidal range of 4.26 m (5.74 m in spring and 2.77 m in neap) before the dyke construction (National Geographic Institute, 1981). Tidal currents then flowed NE–SW with a maximum speed of about 2 knots (Hydrographic Office of Korea, 1990). Significant wave height ($H_{1/3}$) and period ($P_{1/3}$) in the winter season, measured in the vicinity of Piungdo when the dyke construction was in progress, was 5.75 m and 10 sec, respectively (Rural Development Corporation, 1997).

MATERIALS AND METHODS

Approximately 50 line-km of geophysical survey was carried out on August 22-24, 1998 to obtain side-scan sonographs and echograms over the study area aboard a small chartered vessel (Fig. 1). Data acquisition was performed using a C-MAX model CM800 dual side-scan sonar system (100 and 325 kHz) and a Raytheon model DE719D-MK2 digital echosounder. Although the slant scale on the sonographs was reduced to 50 m, it was difficult to obtain sonograph data of good quality in shallow area less than 5 m deep. Positioning was achieved with a DGPS system (Marimatech, model Propak) to an accuracy of 30 cm. Along the tracklines, a total of 42 surface sediment samples were taken with a grab sampler (Fig. 1), and in the laboratory were size-analyzed by sieving (Carver, 1971) and Sedigraph 5100 for the sand and mud fractions, respectively.

Hydrodynamic conditions in the study area were analyzed with a series of current measurements using a rotary-type current meter (Aanderaa, model RCM7), by Rural Development Corporation in September 1992, July 1995, April 1996 and August 1997 (Rural Development Corporation, 1992, 1995, 1996, 1997). Additionally, tide characteristics were derived from continuous measurements of a pressure gauge (Aanderaa, model WLR-7) for the period from February to August 1997 in Hwasan harbor (Fig. 1).

RESULTS

Surface Sediments

Surface sediments in the study area have been investigated by many workers (e.g., Park *et al.*, 1991; Choi, 1992; Choi, 1994), prior to construction of the Saemankuem dyke. The sediment distribution, however, has been changed with a progress of dyke construction. Present sediment types throughout the study area are dominated by sand and muddy sand with local distributions of silty sand, sandy mud and sandy clay (Fig. 2), according to the Folk's (1968) scheme. The surface sediments landward of the dyke are dominated by sands, which extend to about 3.5 km seaward from the dyke. The sandy sediments outside

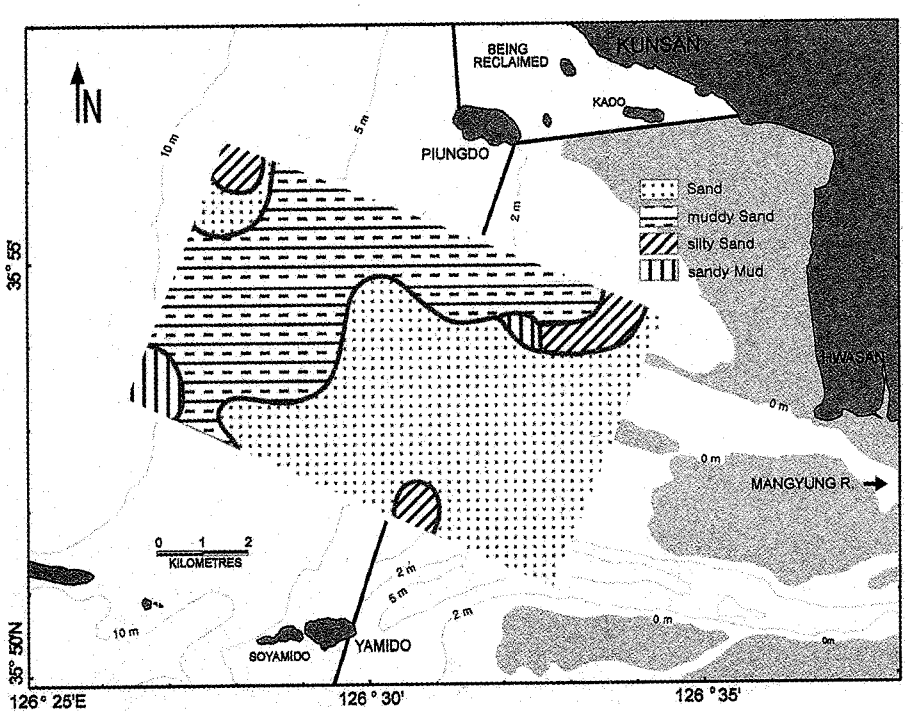

Fig. 2. Spatial distribution of surface sediments in the study area. Sediment types were classified according to the Folks (1968) scheme.

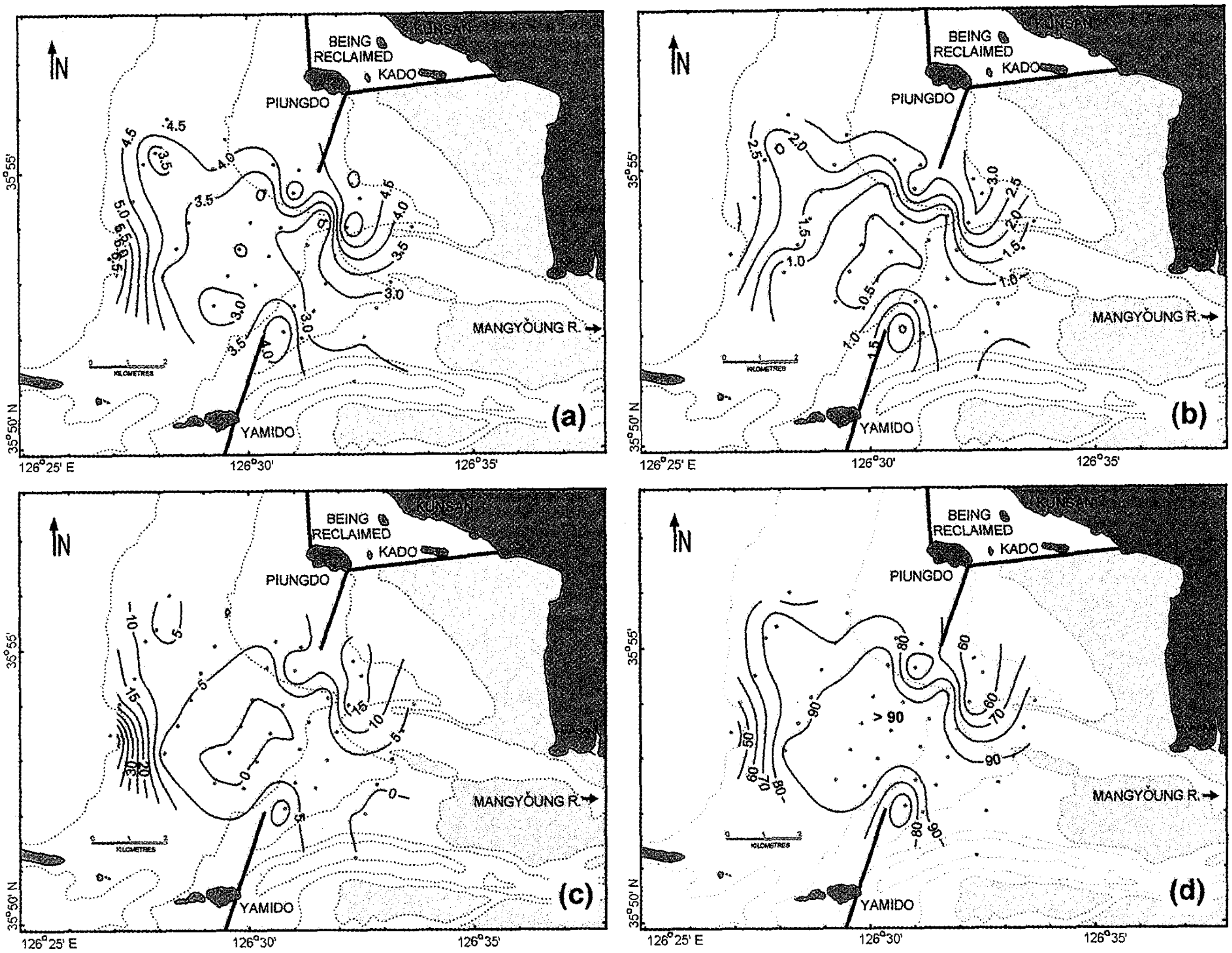

Fig. 3. Distribution of textural parameters of surface sediments in the study area: a) mean grain size (ϕ); b) sorting coefficient (ϕ); c) clay content (%); d) sand content (%).

of the dyke are restricted to the north but connected to the southern sea (Fig. 2), suggesting a possibility of sand transport to the direction of Yamido. On the other hand, relatively fine-grained sediments composed of muddy sands dominate the outside of the dyke and also the northern part inside the dyke.

Figure 3 shows spatial distribution of textural parameters in the study area. The mean grain size varies from 2 ϕ in the tidal channels and sand bar landward of the dyke to 7.4 ϕ in the outermost part seaward of the dyke (Fig. 3a). Sands coarser than 3.0 ϕ are restricted to the central part with the axis in the direction of E–W, and are skirted with very fine sand of 3.0–4.0 ϕ that extends outside the dyke. The sorting coefficient ranges from 0.39 to 3.17 ϕ and is essentially dependent on the mean grain size (Fig. 3b). The best sorted sediment corresponds to areas of fine to very fine sands, i.e. just outside of the dyke. Clay content finer than 8 ϕ is normally less than 10%, except for the southwestern sediments containing over than 20% in the outermost part seaward of the dyke (Fig. 3c). In particular, no content of clay (0%) in the central part around the inter-dyke gap indicates sorting processes by relatively strong tide and wave action passing the artificially-formed inlet. Sand content in the surface sediments shows a wide range of 25.9 to 99.3% (Fig. 3d). The isopleth line of 90% sand delineates a mushroom-shaped body, suggesting that most of the sediments are supplied from the inside of the dyke, i.e. the Mangyung estuary.

Tides and Tidal Currents

Tidal harmonic components in the study area were acquired by harmonic analyses of six-month tide data at Station TM (Fig. 1). The tidal regime is dominated by lunar semidiurnal component because of its near-resonance with Kunsan harbour. The amplitudes of the diurnal K_1 and O_1 components are 34.4 and 26.9 cm, respectively, while semidiurnal M_2 and S_2 components show relatively larger amplitudes of 219.9 and 85.6 cm, respectively. This result illustrates the small diurnal contribution to the tidal range in the Mangyung estuarine system. Similarly the amplitude ratios of the M_1/M_2 and M_4/M_2 are about 0.12 and 0.18, respectively. The neap-spring oscillation is 0.38 times the M_2 amplitude. The diurnal inequality (M_4/M_2) in tidal amplitude is about 0.18–0.27 at Station CM (Fig. 1). The mean tidal range is 4.4 m (6.1 m in spring tide and 2.7 m in neap tide) which is classified as being macrotidal category (Davies, 1984).

The tidal currents of semidiurnal M_2 constituent are dominant flow patterns in the Mangyung estuarine system. The present major and minor directions of tidal ellipses are the east in flood and the west in ebb phase, respectively, with an anticlockwise rotation of the current ellipse. Summary of the tidal-current characteristics, monitored from 1992 to 1997 at the center of the inter-dyke gap (station CM, Fig. 1), is shown in Table 1. With the progress of the dyke construction, tidal currents due largely to semidiurnal M_2 constituent appear to have been changed (Rural Development Corporation, 1995, 1996, 1997). Conspicuously, tidal currents have been pushed to the north and tidal asymmetry in velocity has changed from flood-dominated in 1992 to ebb-dominated condition in 1997 (Table 1). During the periods of November 1992 (natural condition) to in July 1995 (beginning stage of construction), tidal currents flowed in the direction of ENE–WSW and maximum current velocities for each tidal phase were slightly asymmetric with floodward residual currents ranging from 0.02–0.05 m/s. With considerable progress in construction of the dyke extended about 4 km from both Yamido and Piungdo in April 1996, however, ebb-dominated (westward) tidal current asymmetry has been revealed with the maximum speeds of 1.03 and 1.11 m/s in flood and ebb, respectively. Difference of maximum current speeds between reversing flows has become larger as much as 0.29 m/s, with an ebbward residual velocity of 0.15 m/s (279.6 in degree) in August 1997 (Table. 1).

Bathymetry and Bar Morphology

The bathymetric 2–D contours and 3–D surface plot show a marked existence of a tongue-like tidal bar (hereafter named Saemankeum Bar) growing out of the inter-dyke gap between Yamido and Piungdo (Fig. 4). With its axis running parallel to the axis of river mouth in the E–W direction, the Saemankeum Bar is 12 km long and 1.5 km wide on an average, and rises up to 6 m above the surrounding seabed. In contrast, the tidal channels deeper than 5 m, inferred to be formed by flood currents, occur in the northern and southern margins of the bar fringed by the dykes. The interaction of ebb and flood flows through the artificial inlet produces a strong residual flow away from the center but towards the sides of the inlet (e.g., Ludwick, 1974).

The Saemankeum Bar is composed exclusively of moderately- to well-sorted very fine sands (Figs. 2 and 3) and displays an overall lobated form dipping toward the sea, suggesting an active barform. In the innermost part of the survey area the bar is separated into two bodies by a straight channel, i.e. ebb channel, deeper than 2 m extended from the Mangyung River. The separated sand bodies, identified by 0-m contour lines, merge into a sand bar with a flat and broad crest approaching the inter-dyke gap (Fig. 4b). To the outside of the dyke, the distal part of the sand bar looks like a large terminal lobe formed at the outer end of the ebb channel where the expansion of the currents creates an area of deposition, which can be the major part of the ebb tidal delta (e.g., Dyer and Huntley, 1999). Particularly, the broad

Table 1. Maximum and residual tidal currents measured at the depth of 2 m above the seabed in the center of the inter-dyke gap in the northern Saemankeum area.

Date	Maximum Currents (m/s)		Residual Currents		Ellipse Axes (deg.)	
	Flood	Ebb	Vel. (m/s)	Dir. (deg.)	Major	Minor
Sep. '92	0.87	0.77	0.05	69.00	68.00	157.20
July '95	0.81	0.77	0.02	70.00	67.80	158.90
Apr. '96	1.03	1.11	−0.04	277.20	279.00	9.00
Aug. '97	0.99	1.28	−0.15	279.60	276.00	6.00

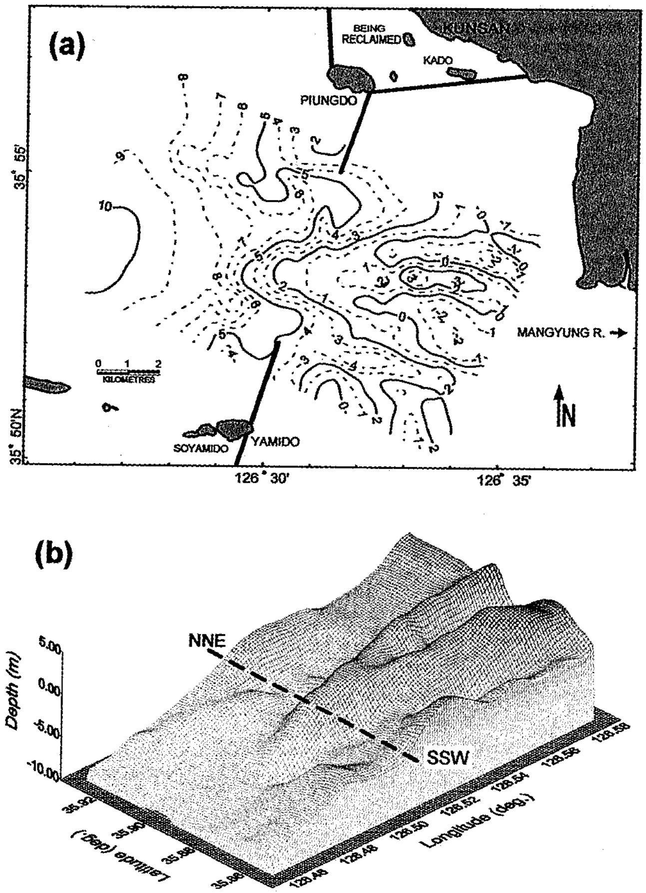

Fig. 4. 2–D and 3–D views of the Saemankeum Bar. The sand bar is projected into the sea through the artificial inter-dyke gap. Contours in the 2–D view (a) are in meters and dashed line in the 3–D view (b) indicates the planned line of dyke construction across the inter-dyke gap.

and flat-topped crest near the inter-dyke gap is considered to be developed by strong wave action (Huthnance, 1982). To the offshore, the sand bar becomes gradually disappeared (about 3 km away from the dyke). The surrounding seafloor consists of 30% clay, 50% silt, and 20% sand with a mean size of 7 ϕ. Here, the tidal flow direction, absolutely normal to the running axis of the bar, may restrict the seaward prograding of the Saemankeum Bar.

Bedforms and Net Sediment Transport Pattern

The characteristics of subaqueous bedforms are dependent upon the availability and grain size of sediments and flow velocity (Stride, 1982). From the sonography data collected, the seabed covered with sands can be divided into three provinces of areas of ripples, megaripples and upper plane bed (Fig. 5). The discrimination between the bedforms is based on their wavelengths and common terms applied for the bedforms in the coastal environment (McCave, 1971; Ashley, 1990). The approximate transition values between ripple and megaripple are 60 cm in wavelength and 4 cm in height (McCave, 1971). The majority of the Saemankeum Bar are covered with megaripples of height <0.5 m and spacing ≅5 m, and upper plane bed. Normally the areas of megaripples occur concurrently with numerous erosional features along the flanks of the sand bar, indicating very strong flow regime capable of eroding and deforming the sand bar. The megaripples appear to increase in scale toward the flat-topped crest of the bar adjacent to the inter-dyke gap, but abruptly disappear to the sea out of the dyke. The upper plane bed normally observed in the tidal channels indicates strong tidal currents, because bed configurations are dependent upon flow velocity and grain size (Southard and Boguchwal, 1973). In spite of the strong tidal currents, larger-scale bedforms, i.e. sand waves with a wavelength greater than 30 m, can not be created because of fine grain size of the sediments smaller than 0.15 mm (very fine sand). On the contrary, no bedform is formed in the offshore with relatively higher content of muddy sediments, in accordance with the relationship between grain size and flow velocity (Southard, 1971; Southard and Boguchwal, 1973).

Net sediment transport pattern illustrated by the asymmetry of the bedforms (e.g., Belderson and Kenyon, 1969; McCave, 1971) are shown in Fig. 6. Most of the transport directions in accordance with the steep face of the bedforms are toward the offshore from the Mangyung River, with some exceptions of opposite direction in the flood channels, i.e. waterways between the Saemankeum Bar and the dykes. The earlier workers postulated that there exists a circulation of sand around a tidal sandbank, with movement over the crest from the gentle to the steeper slope where accretion occurs (Houbolt, 1968; Caston, 1972). However, the net sediment transport pattern on the Saemankeum Bar (Fig. 6) shows a dominant westward component of the sand transport, especially in the vicinity of the dyke, indicating a different mechanism forming the ebb tidal bar.

DISCUSSIONS

Growth Rate of Saemankeum Bar

In consideration of relatively short course (98 km)

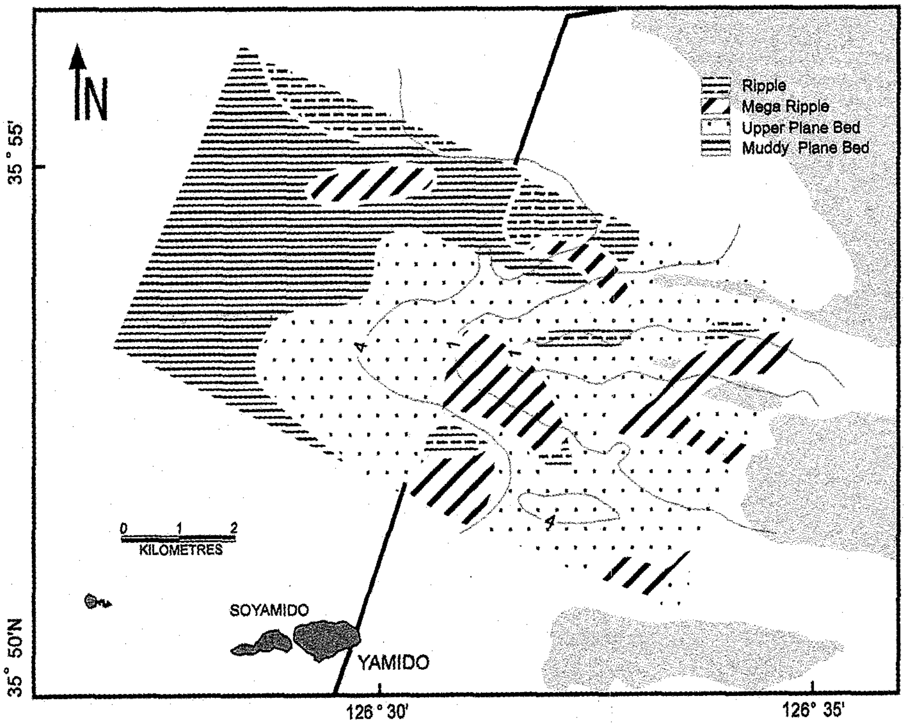

Fig. 5. Spatial distribution of bedforms over the study area recognized from the side-scan sonographs. Contours overlaid in the map indicate water depths in meters.

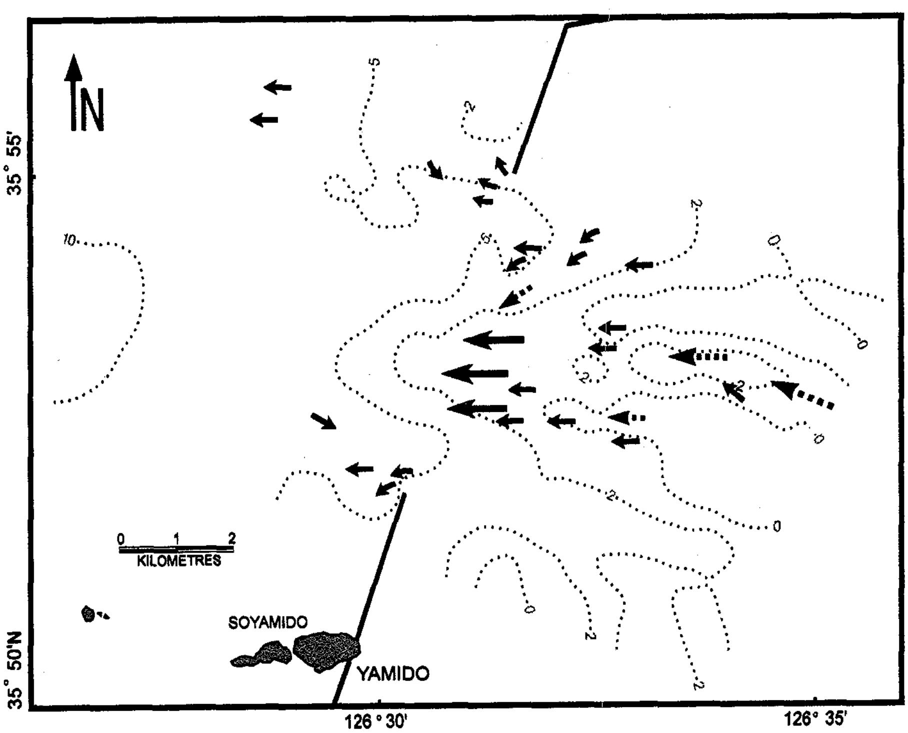

Fig. 6. Sediment transport paths judged from the foreset direction of bedforms. Arrows illustrae net sediment transport (e.g., Belderson and Kenyon, 1969; McCave, 1971). Contrours in the map are water depths in meters.

of the Mangyung River and the macrotidal range of up to 6 m, the Mangyung estuary may belong to a partially mixed estuary (Pritchard, 1955), where river flows do not dominate the estuarine circulation. In this setting, tidal currents play a significant role in distributing riverine sands as tidal bedforms and sand bar. Before construction of the Saemankeum dyke, tidal currents would remold riverine sands into tidal sand ridges or bars in the same direction as that of the major tidal flows, NE–SW. In addition, near-symmetry of tidal current speeds constrained the seaward extension of the sand deposits within 20 km of the

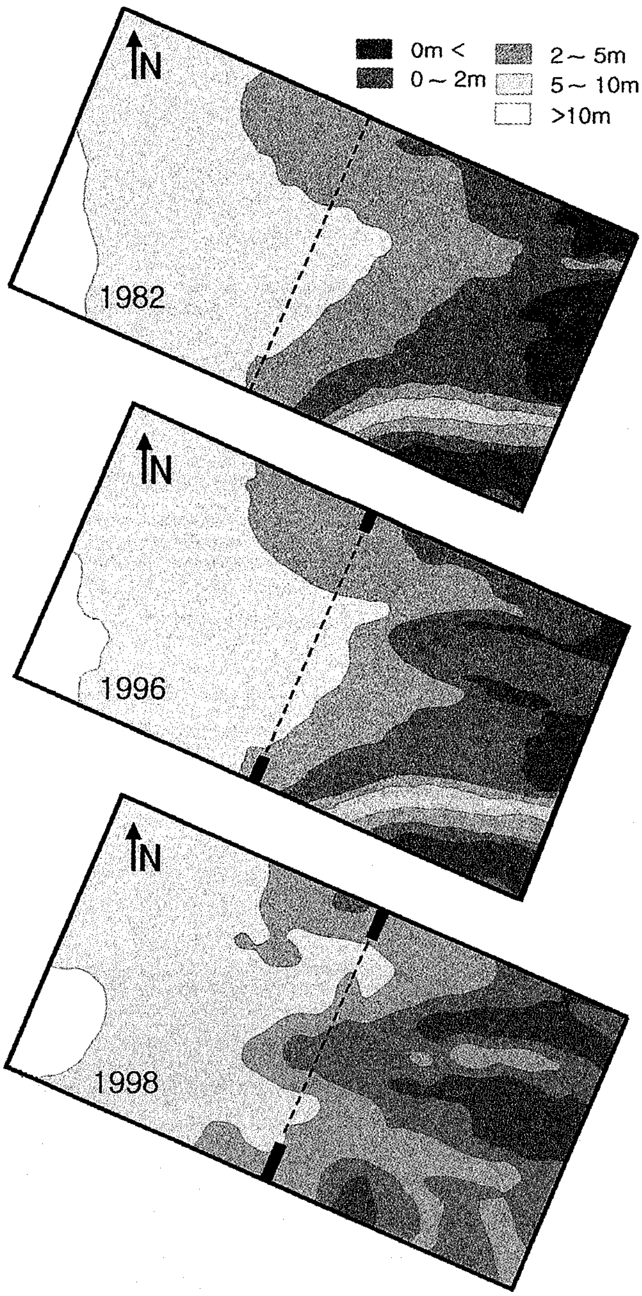

Fig. 7. Comparison of historical charts during the period from 1982 to 1998.

shore. Winter-monsoon waves from north to northwest appear to have littorally transported appreciable amounts of sands to the south.

However, in progress of the Saemankeum dyke construction, the estuarine environment has been greatly changed in hydrodynamics. Ebb flows have become highly stronger over the flood currents, particularly at the inter-dyke gap. With the main flow direction varied from NE–SW to E–W, the southward littoral drift of the sands has already been blocked by the dykes. Instead, a tidal sand bar at the river mouth has been preferably activated to advance westward, fed by a single, straightened tidal channel, like a prograding ebb tidal-delta lobe built by an active distributary ebb channel in the natural tidal inlet. Comparison of bathymetric charts for the past 16 years shows a remarkable development history of the Saemankeum Bar (Fig. 7). In comparison with the bathymetric chart of 1982, the 1996 chart exhibits a clear sign of the bar formation and the post-1996 (1998) chart shows its fast growing through the artificially formed inlet. On the basis of the comparison of the historical charts and present results, the prograding rate of the Saemankeum Bar can be roughly estimated at 1.63 km/yr for the last three years (1996-1998). Such a fast growing would be attributed to the ebb-dominated hydrodynamic regime caused by the artificially formed inter-dyke gap. On the other hand, asymmetry of tidal current regime enhanced by river flow in ebb phase can also be notified by difference in scouring around the basal rocks artificially arranged 1.8 m high above the surrounded seabed on the inter-dyke gap (Fig. 8). An echo-sounding profile across the inter-dyke gap clearly shows the characteristic features differently scoured at each side of the basal rocks (Fig. 8a). This phenomenon is considered to be due to the difference in strengths of eddies generated at each tidal phase (Fig. 8b).

Sediment Transport after Completion of Dyke Construction

The artificial structure of dykes with an inter-dyke gap well resembles a natural system of barrier islands with a tidal inlet off the river mouth. In this analogy, the bar head out of the inter-dyke gap may be regarded as an ebb tidal delta. Sedimentology and morphodynamics of the barrier-island system have been extensively studied from numerous examples in the eastern U.S. coastal region (cf. Reinson, 1992). Through the inter-dyke gap suspended sediments from the Mangyung River also empty into the adjoining shoreface; before the dyke construction, these were laden in a suspension plume flowing along the coast toward the south of Yamido. The suspended sediments from the Keum and Mangyung rivers are considered to be the major source of the giant mud deposit, "Huksan Mud Belt", offshore the southwest coast of Korea (Lee and Chough, 1989; Lee and Chu,

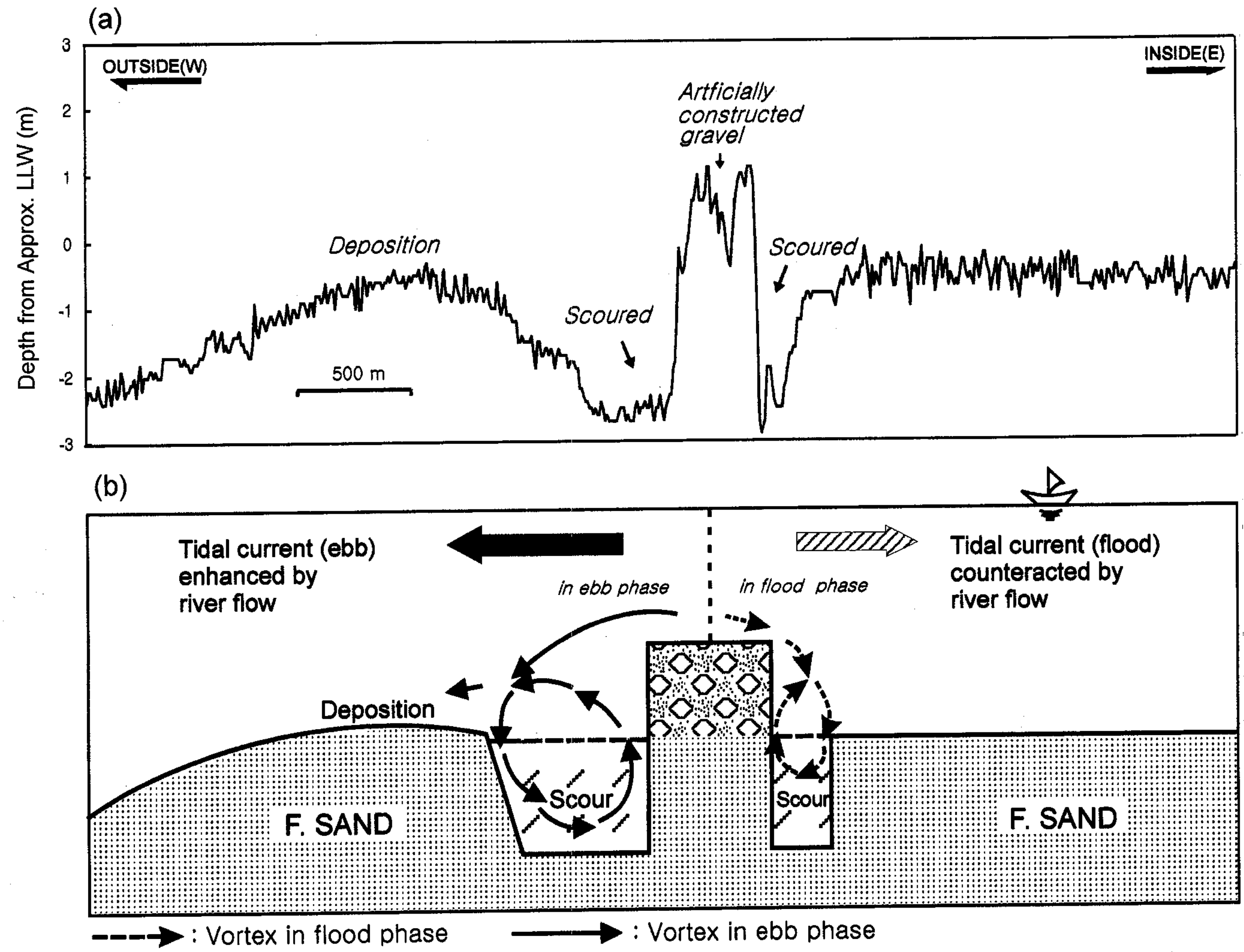

Fig. 8. Echogram taken across the inter-dyke gap (a), and conceptual model illustrating the differential scouring at each side of the artificial gravel dam (b). The projected part upward in the center of the scoured area is artificially formed gravel dam for constructional base of the dyke.

2001). In addition, the exposed transgressive muds on the seafloor seaward of the dyke might also contribute significant amounts of suspended matter through tidal eroding. If this is true, the continuous armoring of the muds with the prograding sands from the Mangyung River would result in appreciably diminishing accretional rates of the Huksan Mud Belt. However, the present lobate bar-head sands will be redistributed by strong NE–SW flowing tidal currents along the dykes without further supplies after the dykes have been completed. Although this isolated sand deposit may be gradually transported along the dykes southward over the transgressive muds (Fig. 2), the sandy nearshore and beach present south of the dykes would be eventually put into a non-depositional or even erosional phase in the geologically near future. By contrast, in some sheltered places in the immediate vicinity of the dykes, mud accumulations may have already begun to be under lowered energy conditions. So, further detailed study on sediment transport should be carried out to convince how the sedimentary environment will be affected after completion of the dyke construction.

CONCLUSIONS

The Saemankeum dyke under construction since 1992 in the Mangyung and Dongjin estuarine environments, has raised enormous changes hydrodynamic and sedimentological during the past few years. Especially the inter-dyke gap in the northern Saemankeum area has acted as an artificial tidal inlet, causing the tidal current regime to be reversed from being flood- to ebb-dominated with a directional change from NE–SE to E–W. Due to such a change in hydraulic regime, a tongue-like tidal sand bar, the Saemankuem Bar, composed of well-sorted very fine sands (3.0–3.5 ϕ), began to prograde offshore through the inter-dyke gap as like an ebb tidal delta. The Saemankeum Bar, parallel to the direction of the tidal current maxima, extends up to 3 km seaward out of the dyke. The prograding rate of the sand bar is estimated to be about 1.63 km/yr during the past three years (1996–1998). Such a rapid prograding of tidal sand bar is attributed to enhanced sediment supply by the degradation of former tidal sand bars in the Mangyung estuarine environment. The reworking of the tidal sand bars also caused the pre-existing tidal channels to be wider, deeper and more straightened. However, after completion of the dykes, the remnant of the Saemakeum Bar outside the dyke is likely to be disintegrated and transported to the south instead of farther seaward growth, because of littoral transport absolutely normal to the axis of the bar.

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REFERENCES

Ashley, G.M., 1990. Classification of large-scale subaqueous bedforms: a new look at an old problem. Jour. Sed. Petrol., **60**: 160–172.

Belderson, R.H. and Kenyon, N.H., 1969. Direct illustration of one way sand transport by tidal currents. Jour. Sed. Petrol., **39**: 1249–1250.

Carver, R.E., 1971. Procedures in Sedimentary Petrology. Wiley, New York, 653 pp.

Caston, V.N.D., 1972. Linear sand banks in the southern North Sea. Sedimentology, **18**: 63–78.

Choi, J.G., Lee, E.H., Noh, J.H., and Huh, S.H., 1999. The study on the phytoplankton bloom and primary productivity in lake Shihwa and adjacent coastal areas. Jour. Korean Soc. Oceanogr. [The Sea], **2**: 78–86.

Choi, K.S., 1994. Sedimentological study of the sea floor deposits off the Mangyung-Dongjin river estuary, west coast of Korea, Unpublished Msc. Thesis, Seoul National Univ., 183 pp.

Choi, O.I., 1992. Sedimentation in the nearshore zones (intertidal and subtidal) of the Dongjin and Mangyung Rivers, west coast of Korea, Unpublished Msc. Thesis, Seoul National Univ., 69 pp.

Dyer, K.R. and Huntley, D.A., 1999. The origin, classification and modeling of sand banks and ridges. Cont. Shelf Res., **19**: 1285–1330.

Folk, R.L., 1968. Petrology of sedimentary rocks. The University of Texas, Texas, 170 pp.

Houbolt, J.J.H.C., 1968. Recent sediments in the Southern Bight of the North Sea. Geologie en Mijnbouw, **47**: 245–273.

Huthnance, J.M., 1982. On one mechanism forming linear sand banks. Jour. Fluid Mech., **69**: 689–704.

Hydrographic Office of Korea, 1990. Tide Tables, 22 pp.

Klein, G.D., Park, Y.A., Chang, J.H., and Kim, C.S., 1982. Sedimentology of a subtidal, tide-dominated sand body in the Yellow Sea, southwest Korea. Marine Geology, **50**: 221–240.

Kunsan University, 1994. A Study on the Compensation for Fisheries Damage Caused by Comprehensive Development of the Saemankeum Area, Part IV Marine Geological Study. 364 pp.

Lee, H.J. and Chough, S.K., 1989. Sediment distribution, dispersal and budget in the Yellow Sea. Mar. Geol., **87**, 195–205.

Lee, H.J. and Chu, Y.S., 2001. Origin of inner-shelf mud deposit in the southeastern Yellow Sea: Hukšan Mud Belt. Jour. Sed. Res., **71**: 144–154.

Lee, H.J., Chu, Y.S., and Park, Y.A., 1999. Sedimentary processes of fine-grained material and the effects of seawall construction in the Daeho macrotidal flat-nearshore area. Mar. Geol., **157**: 171–184.

Lee, T.W., Moon, H.T., and Huh S.H., 1999. Changes of species composition of fish in polluted lake Shihwa and adjacent coastal area. Jour. Korean Soc. Oceanogr. [The Sea], **2**: 110–116.

Ludwick, J.C., 1974. Tidal currents and zig-zag sand shoals in a wide estuary entrance. Geological Society of America Bulletin, **85**: 717–726.

McCave, I.N., 1971. Sand waves in the North Sea off the coast of Holland. Marine Geology, **10**: 199–225.

National Geographic Institute, 1981. A Report of Fundamental Study in Coastal Area (Kogunsan Islands).

Off, T., 1963. Rythimic linear sand bodies caused by tidal currents. Bull. Am. Ass. Petrl. Geol., **47**: 324–341.

Park, Y.A., Kang, H.J. and Song, Y.I., 1991. Sandy sediment transport mechnism on tidal sandy bodies, west coast of Korea. The Korean Jour. Quaternay Research, **5**: 33–46.

Park, S.C. and Lee, S.D., 1994. Depositional patterns of sand ridges in tide-dominated shallow water environments: Yellow Sea coast and South Sea of Korea. Mar. Geol. **120**: 89–103.

Park, S.C. and Yoo, D.G., 1997. Bedform distribution and sand transport trend on a subtidal sand ridge in a macrotidal bay, west coast of Korea. Jour. Korean Soc. Oceanogr., **32**: 181–190.

Pritchard, P.W., 1955. Estuarine circulation patterns. Proc. Amer. Soc. Civil Engr., **81**: 717-1-717-11.

Reading, H.G., 1996. Sedimentary Environments: Processes, Facies and Stratigraphy. Blackwell Science, Cambridge, 688 pp.

Reinson, G.E., 1992. Transgressive barrier island and estuarine systems. In: Facies Models: Response to Sea-level Change, edited by Walker, R.G. and N.P. James, Geol. Ass. Can., Waterloo, Ontario, pp. 179–194.

Rural Development Corporation, 1992. A Report on Hydraulic Study and Wave Measurement in the Seamankeum Area. 611 pp.

Rural Development Corporation, 1995. A Report on Hydraulic Study and Wave Measurement in the Seamankeum Area. 693 pp.

Rural Development Corporation, 1996. Tideland Reclamation in Korea. Rural Development Corporation, Yiwang, Kyunggido, 405 pp.

Rural Development Corporation, 1997. A Report on Hydraulic Study

and Wave Measurement in the Seamankeum Area. 693 pp.
Rural Development Corporation, 1998. A Report on Hydraulic Study and Wave Measurement in the Seamankeum Area. 489 pp.
Rural Development Corporation, 1999. A Report on Hydraulic Study and Wave Measurement in the Seamankeum Area. 853 pp.
Southard, J.B., 1971. Representation of bed configuration in depth-velocity-size diagrams. J. Sed. Petrol., **41**: 903–915.
Southard, J.B. and Boguchwal, L.A., 1973. Flume experiments on the transition from ripples to lower flat bed with increasing sand size. Jour. Sed. Petrol., **43**: 1114–1121.
Stride, A.H., 1982. Offshore tidal sands. Chapman and Hall, London, 222 pp.

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